

Experimental studies of neutral current pion production at low energy

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Outline

- Introduction
 - Neutral Current (NC) π production
- Motivation
- Recent results
 - K2K, MiniBooNE
- On-going and Future experiments
 - SciBooNE
 - MINERvA

Neutral current π production

- NC π production processes;

- Resonant**

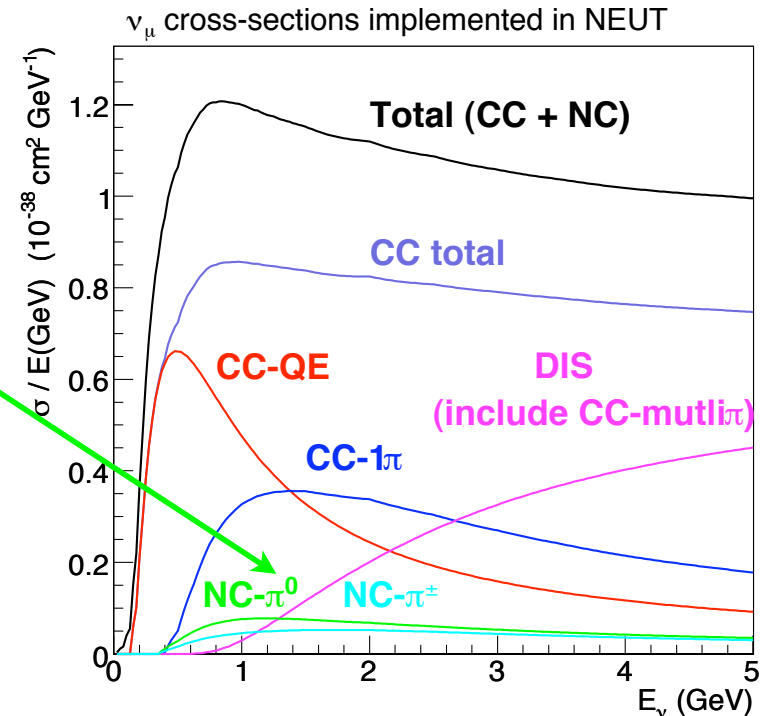
- $\nu + N \rightarrow \nu + N^* \rightarrow \nu + N' + \pi^{\pm,0}$
 - prominent resonance = $\Delta(1232)$

- Coherent**

- $\nu + A \rightarrow \nu + A + \pi^0$

- DIS (multi- π prod.)**

- $\nu + N \rightarrow \nu + \pi + X$



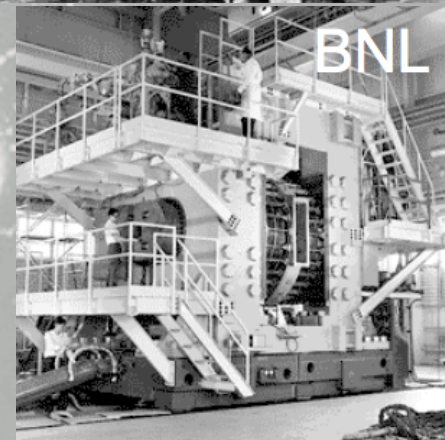
NEUT prediction

NC single π production (NC-1 π);

Predominant in “**low energy**” region (\equiv few-GeV)

Past ν interaction measurements

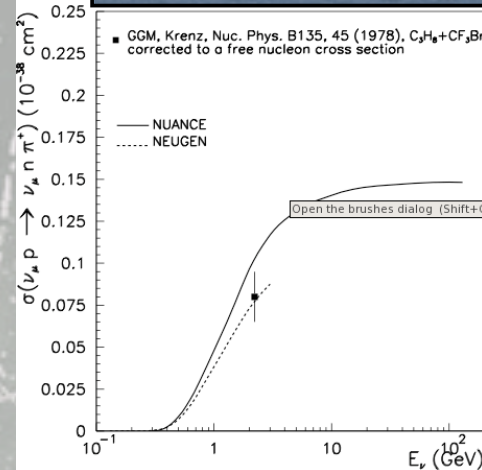
- Most of present knowledge of neutrino cross sections come from bubble chamber ('70-'80.)
- CERN, BNL, ANL, FNAL etc.
- Providing important constrain for simulation
- Although...
 - Low statistics; 100s events
 - Systematic uncertainties
 - Light targets: H_2 , D_2 , etc



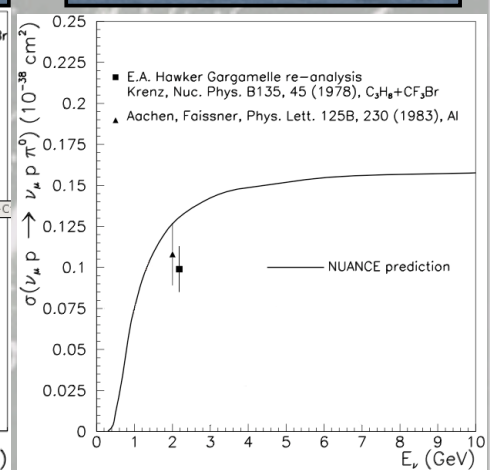
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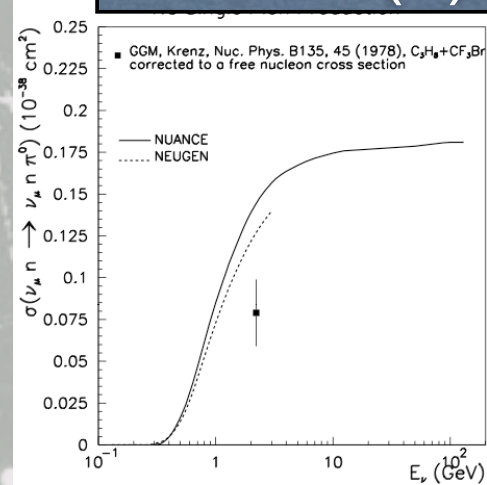
NC- $1\pi^+$ (n)



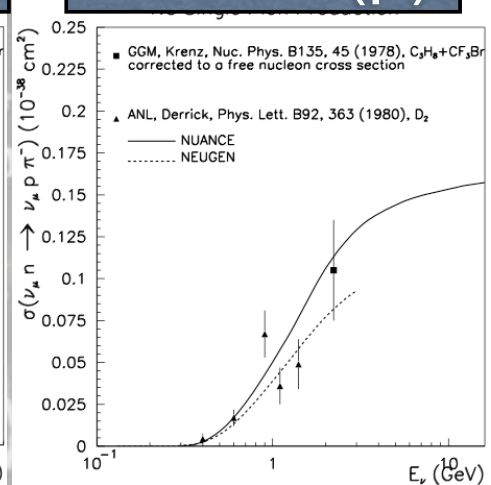
NC- $1\pi^0$ (p)



NC- $1\pi^0$ (n)



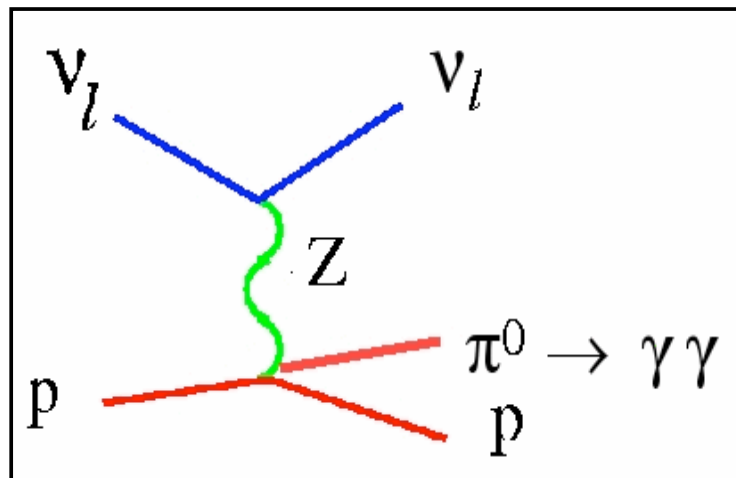
NC- $1\pi^-$ (p)



Recent $\sigma(\nu)$ measurements...

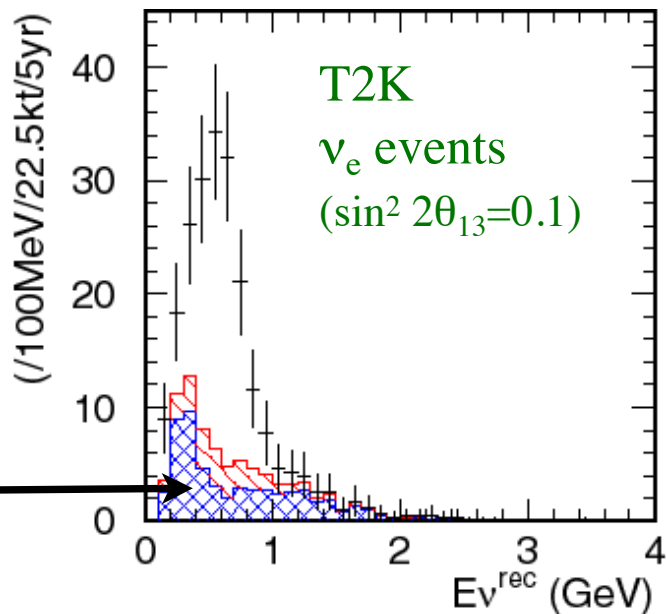
- Recent efforts for measurement of NC cross section at low energy are toward ν oscillation experiments (T2K, NOvA).
- Especially, focused on **NC- $1\pi^0$** production with **nuclear target**.

NC- $1\pi^0$ (e.g. resonance)

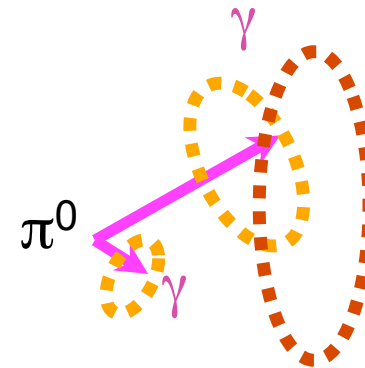


Impact of $\text{NC-}1\pi^0$ cross section to ν oscillation

$\text{NC-}1\pi^0$ is a dominant background to ν_e appearance search



- Signal: CC-QE ($\nu+n\rightarrow e+p$)
- Background
 - Beam ν_e
 - **$\text{NC-}1\pi^0$**

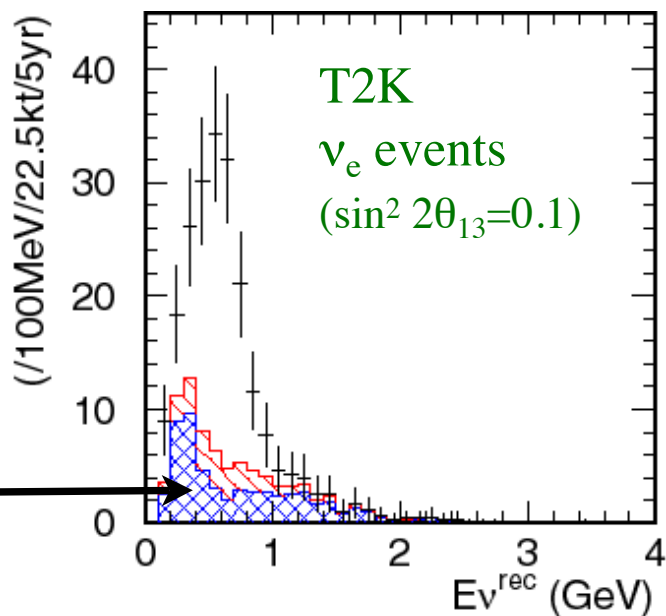


$\pi^0\rightarrow\gamma\gamma$ makes similar signature to ν_e events (e.g. $\nu_e+N\rightarrow e+N'$);
one fuzzy Cherenkov ring

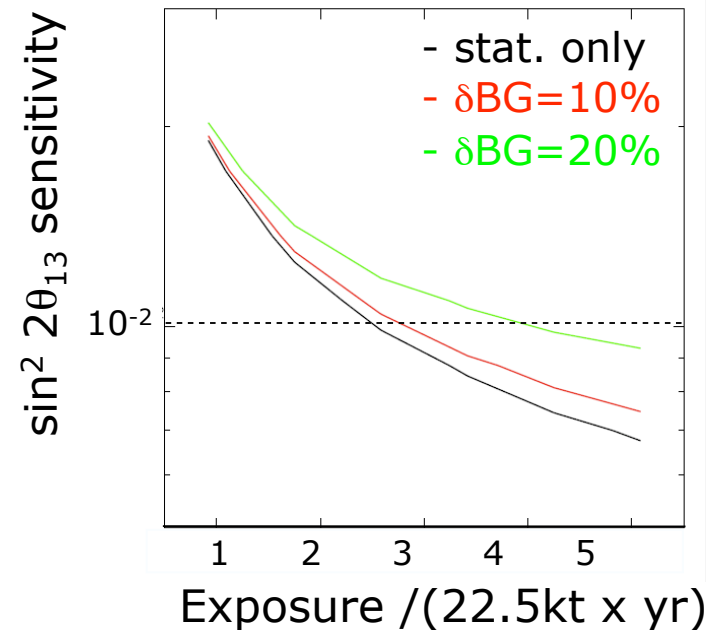
- Overlapping two rings
- Asymmetric decay of π^0 (only one γ detected)

Impact of NC- $1\pi^0$ cross section to ν oscillation

NC- $1\pi^0$ is a dominant background to ν_e appearance search



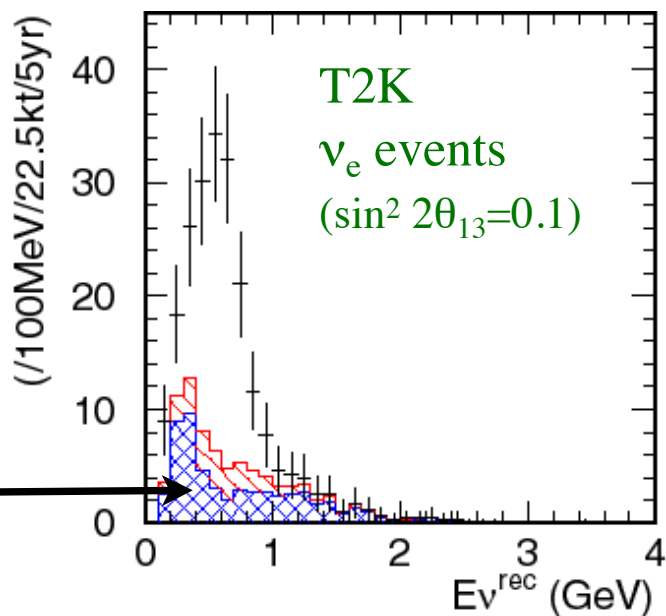
- Signal: CC-QE ($\nu+n\rightarrow e+p$)
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 - **NC- $1\pi^0$**



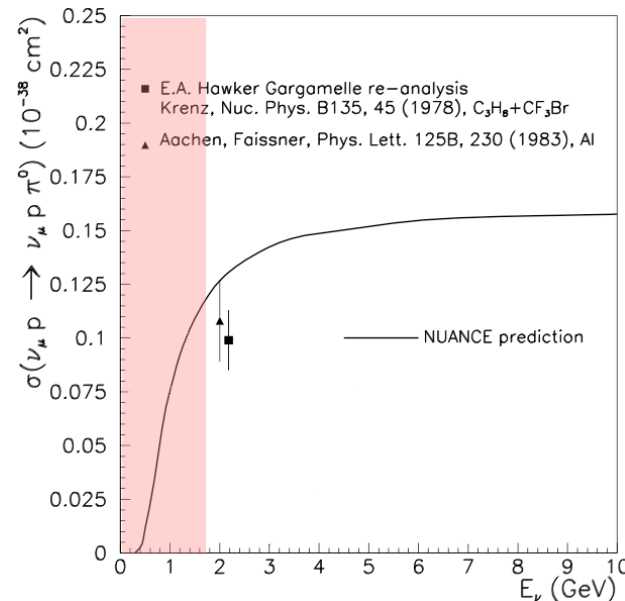
T2K needs to know NC- $1\pi^0$ cross section at 10% level.

Impact of NC- $1\pi^0$ cross section to ν oscillation

NC- $1\pi^0$ is a dominant background to ν_e appearance search



- Signal: CC-QE ($\nu+n \rightarrow e+p$)
- Background
 - Beam ν_e
 - **NC- $1\pi^0$**



- Two measurements at 2 GeV
 - Statistics < 500 events
- <1GeV is threshold of π production
 - No measurement in this region.
 - **→ Need new measurement!**

New Neutrino Data

- New data: order of magnitude higher statistics
- Present: new low energy ($\sim 1\text{GeV}$)
 - **K2K-1KT** (1999 - 2004)
 - **MiniBooNE** (2002 - present)

} Cherenkov detector
- Coming soon: $\sigma(\nu)$ dedicated programs
 - **SciBooNE** (2007- present)
 - **MINER ν A** (2009)

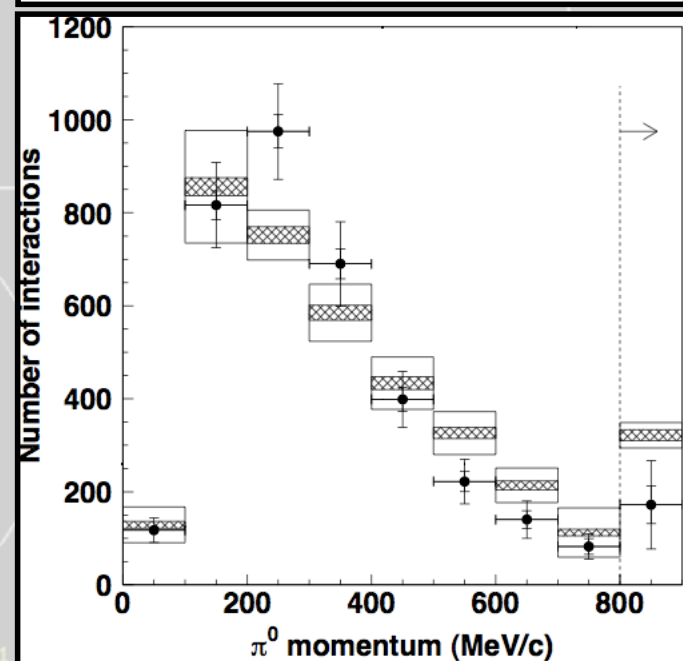
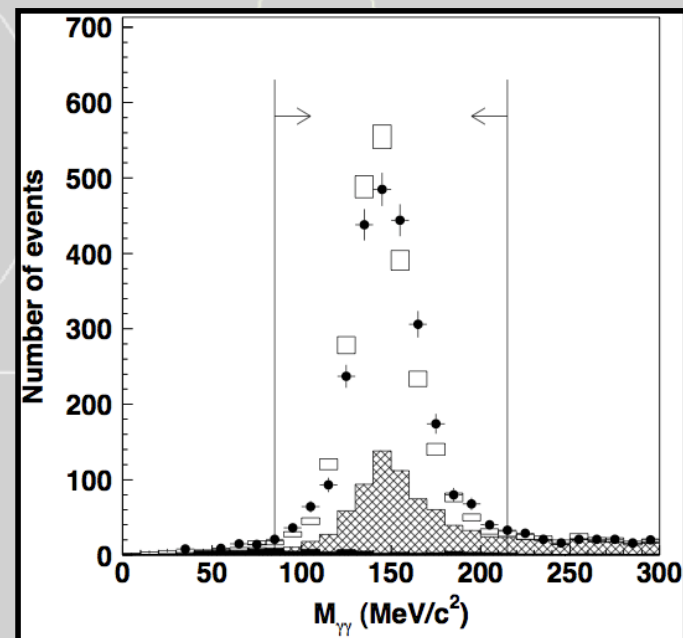
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NC- $1\pi^0$ meas. by K2K-1KT

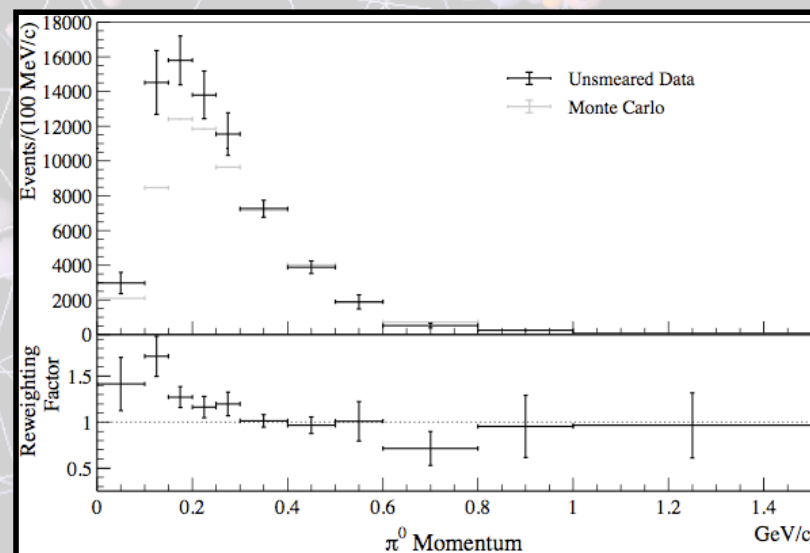
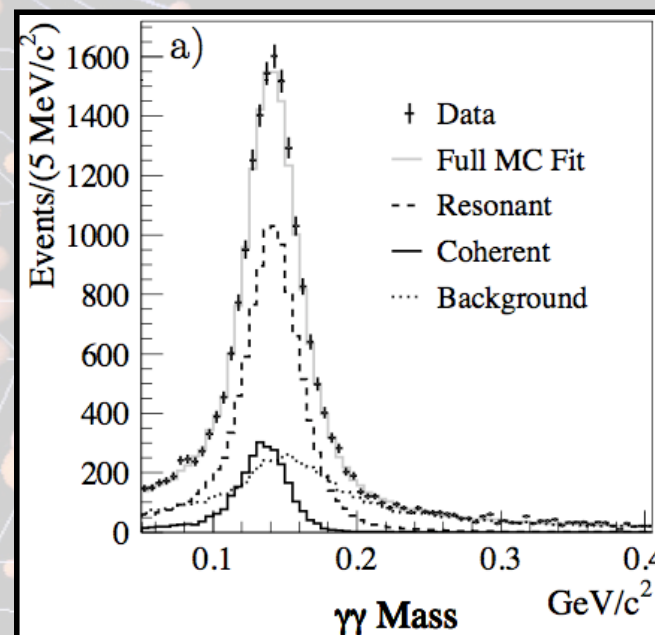
- 1KT detector: K2K near detector
 - 1,000 ton water Cherenkov
- Neutrino energy: 1.3 GeV
- 1st meas. of NC- $1\pi^0$ prod. in H₂O
Physics Letters B619, 255 (2005)
- **2,496 NC- π^0 sample**
 - NC- $1\pi^0$ purity (in $1\pi^0$ sample): 71%
 - Resonance: 52%
 - Coherent: 10%
 - Final state interaction: 7%
- $\sigma(\text{NC}1\pi^0)/\sigma(\text{CC}) = (6.4 \pm 0.1 \pm 0.7)\%$
- NEUT prediction: 6.5%
- Good agreement with expectations
- Momentum distribution disagrees



51.6 55.5 59.3 63.1 66.9 70.8 74.6 78.4 82.3 86.1

NC- $1\pi^0$ meas. at MiniBooNE

- MiniBooNE detector at FNAL
 - 800 ton mineral oil (CH_2) Cherenkov
- Neutrino energy: 0.7 GeV (peak)
- 1st measurement of NC coherent- π^0 below 2 GeV Phys. Lett. B664, 41 (2008)
- **28,000 NC- $1\pi^0$ events**
 - S/N~30
- Coherent fraction in NC- $1\pi^0$;
 $N_{\text{coh}}/(N_{\text{coh}} + N_{\text{res}}) = (19.5 \pm 1.1 \pm 2.5)\%$
- Model predicted (Rein-Sehgal) 30% fraction.
- 1.5 times lower than default prediction.
- Higher production rate wrt predictions at low π^0 momentum.

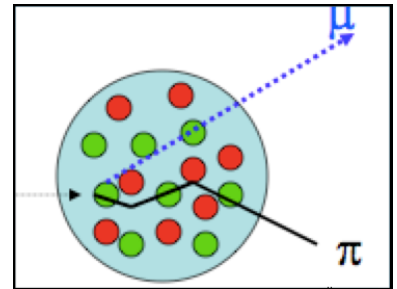


New issues...

- Thanks to recent high statistics and precision measurements, we discovered new issues.

- π^0 momentum

- K2K-1KT (H_2O) found disagreement with predictions.
- MiniBooNE (CH_2) found higher π^0 prod. rate wrt prediction at low momentum region.
- → Nuclear effect??



→ Important for oscillation experiments.

- Coherent- π production

- MiniBooNE found evidence of ν NC-coh. π^0
 - Also $\bar{\nu}$ NC- π^0 sample suggests evidence of NC-coh. π^0 (arXiv:0806.2347)
- K2K-SciBar found no evidence of CC-coh. π^+ (PRL**95**, 252301 (2005))

→ Interesting in their own.

→ Need dedicated $\sigma(\nu)$ experiments

Dedicated $\sigma(\nu)$ experiments

- Use **fine-grained detector** + calorimeter
 - Clear identification of final state of ν interactions
 - Reconstruct all final state particles
- **SciBooNE** (2007 - present)
 - Neutrino energy: 0.7 GeV (flux peak) @FNAL BNB
 - CH target
 - Both ν and $\bar{\nu}$
- **MINER ν A** (2009)
 - Neutrino energy: Peak $E_\nu = 3 - 12$ GeV @FNAL NuMI
 - Nuclear targets (He, C, Fe, Pb)
 - Allow detailed study of nuclear effect in ν 's for the first time
 - Data taking starts 2009 - detector construction in progress!

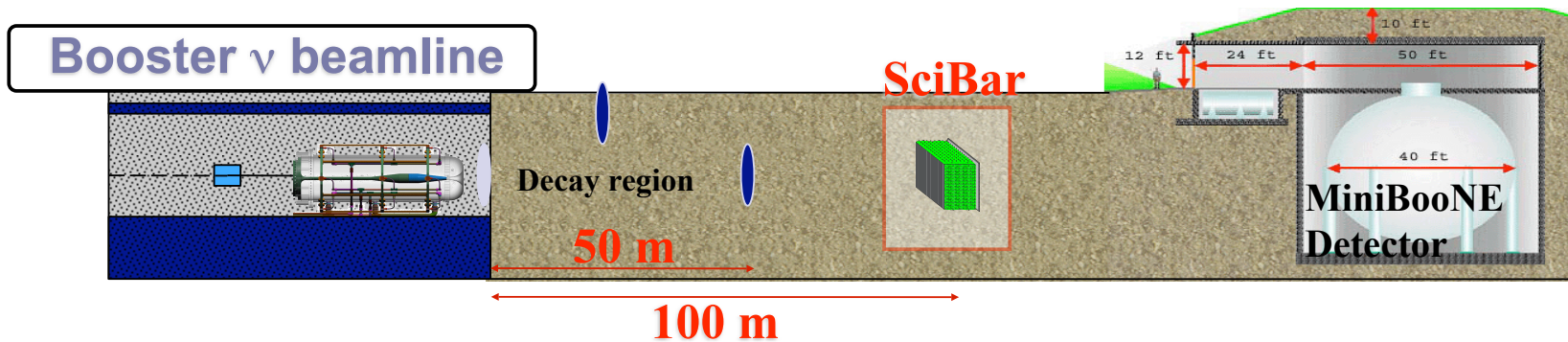
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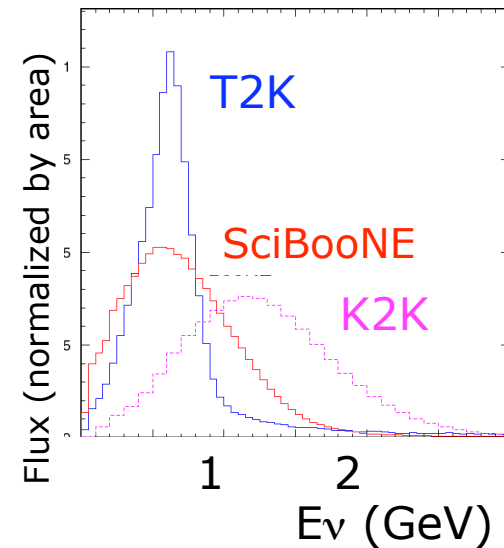
SciBooNE Experiment

SciBooNE Experiment

(K2K-SciBar detector at FNAL Booster Neutrino Beam line)

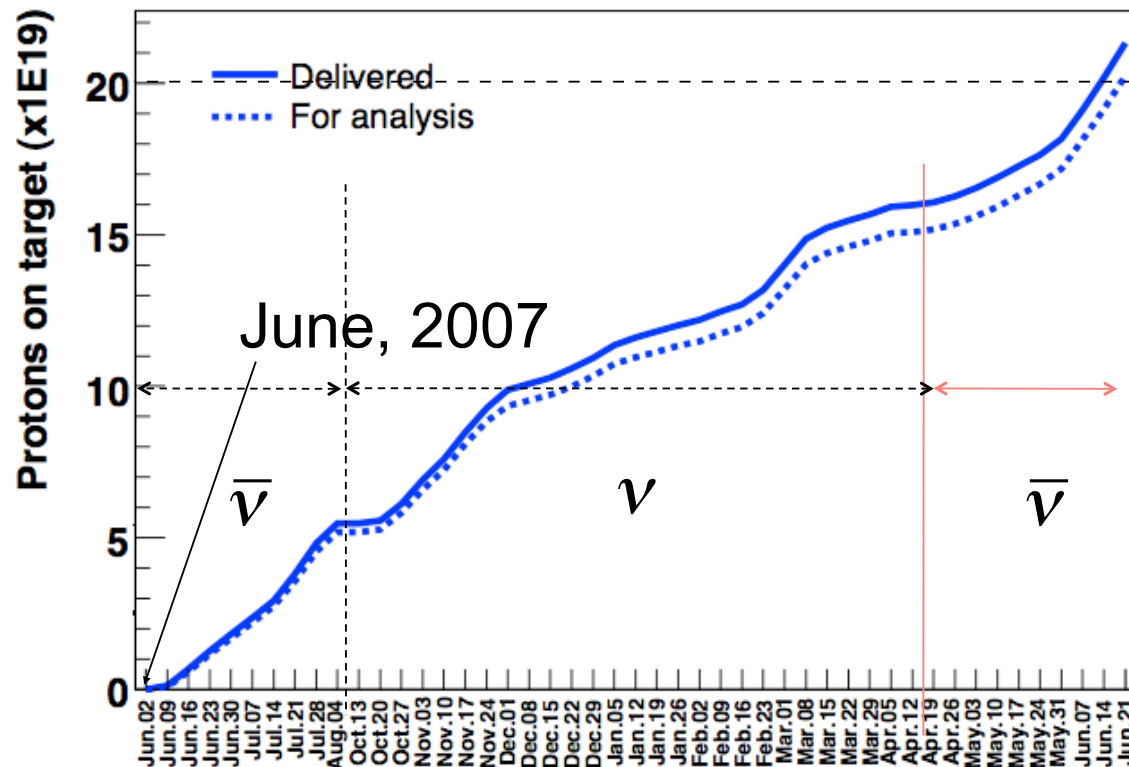


- Precision measurement of ν & $\bar{\nu}$ cross sections at $\sim 1\text{GeV}$.
- **SciBar:**
 - Originally K2K-near detector
 - Shipped to FNAL from KEK
- **BNB: Intense & low energy ν beam**
 - E_ν good match to T2K
 - Quick & high stat. measurement (SciBooNE results before T2K starts)
 - ν and $\bar{\nu}$ beam



Data taking status

- Projected Protons On Target (POT): $2E20$
 - Total collected POT: $>2E20$
 - ν : $\sim 1E20$ (goal: $1E20$) → completed in Apr. '08
 - $\bar{\nu}$: $>1E20$ (goal: $1E20$) → crossed goal in Jun. '08
- Continue data taking until Aug.



Data taking
is ongoing.

SciBooNE detectors

SciBar: Fully active target & tracker

Total mass: 15t, Fiducial: ~10t

14,336 channels; extruded scintillator

Particle ID with dE/dx

EC: EM calorimeter

Lead+scintillation fibers: $11X_0$

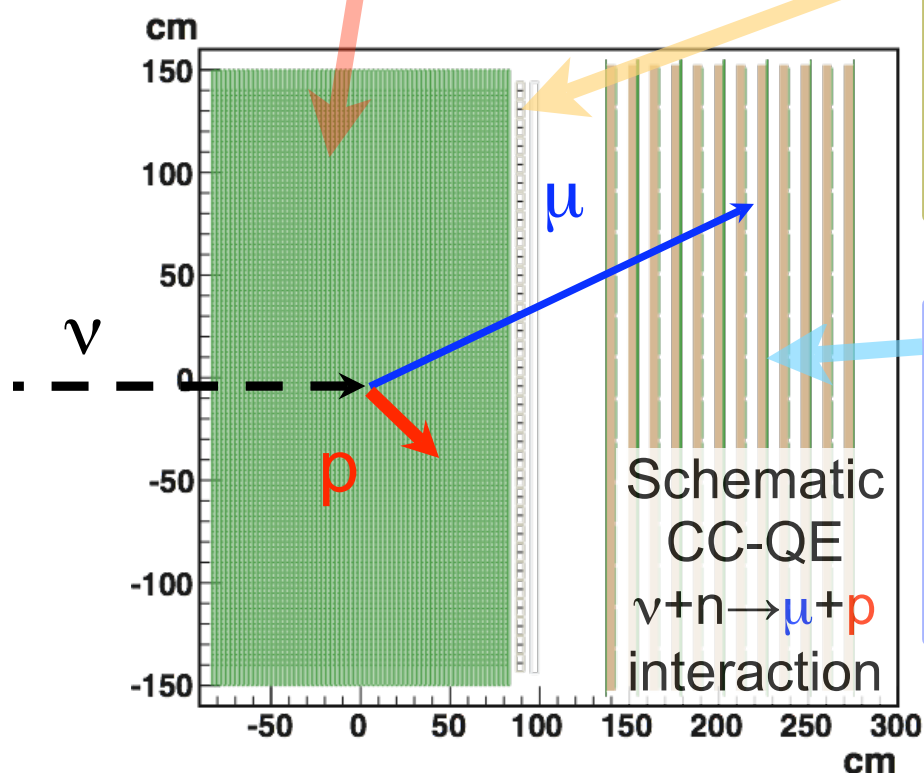
Gamma / electron ID

MRD: Muon Range Detector

Steel (5cm thick x12) +scintillator

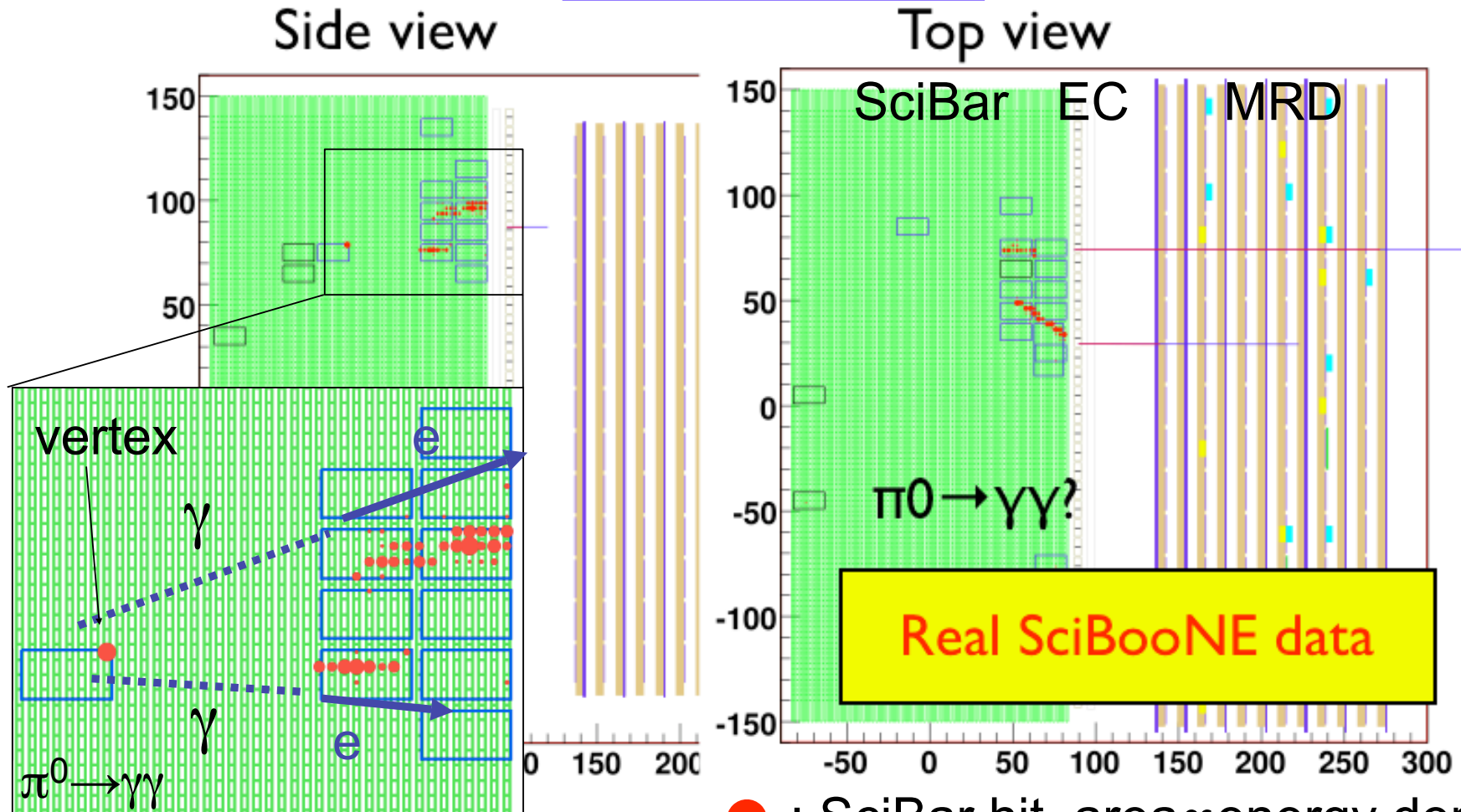
μ identification

Measure up to 1.2 GeV/c



NC- $1\pi^0$ event candidate

$$\nu + p \rightarrow \nu + p + \pi^0$$



● : SciBar hit, area \propto energy deposit

□ : SciBar TDC hit

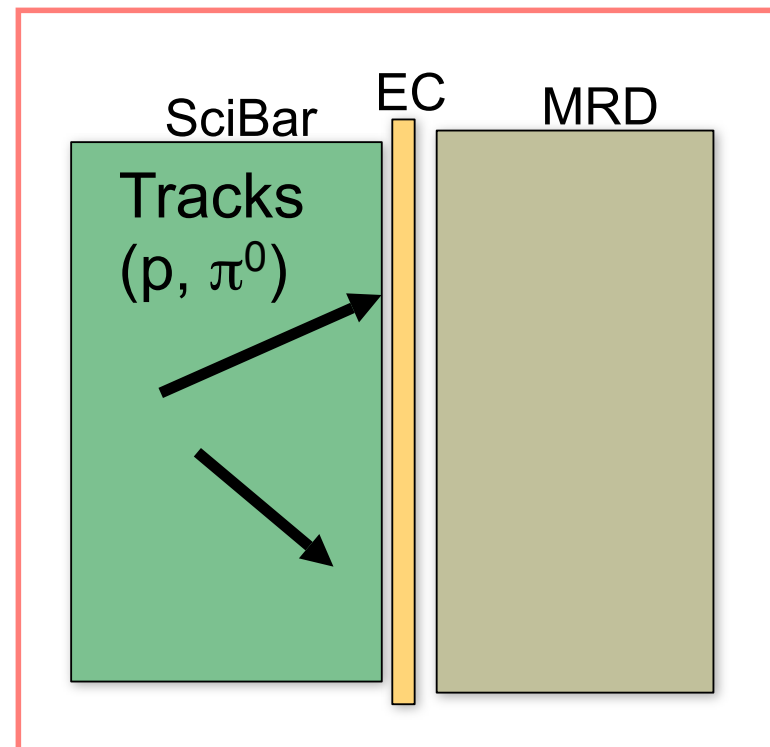
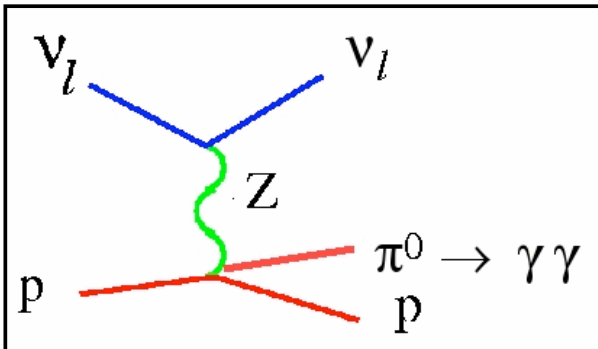
NC- π^0 study at SciBooNE

Preliminary results

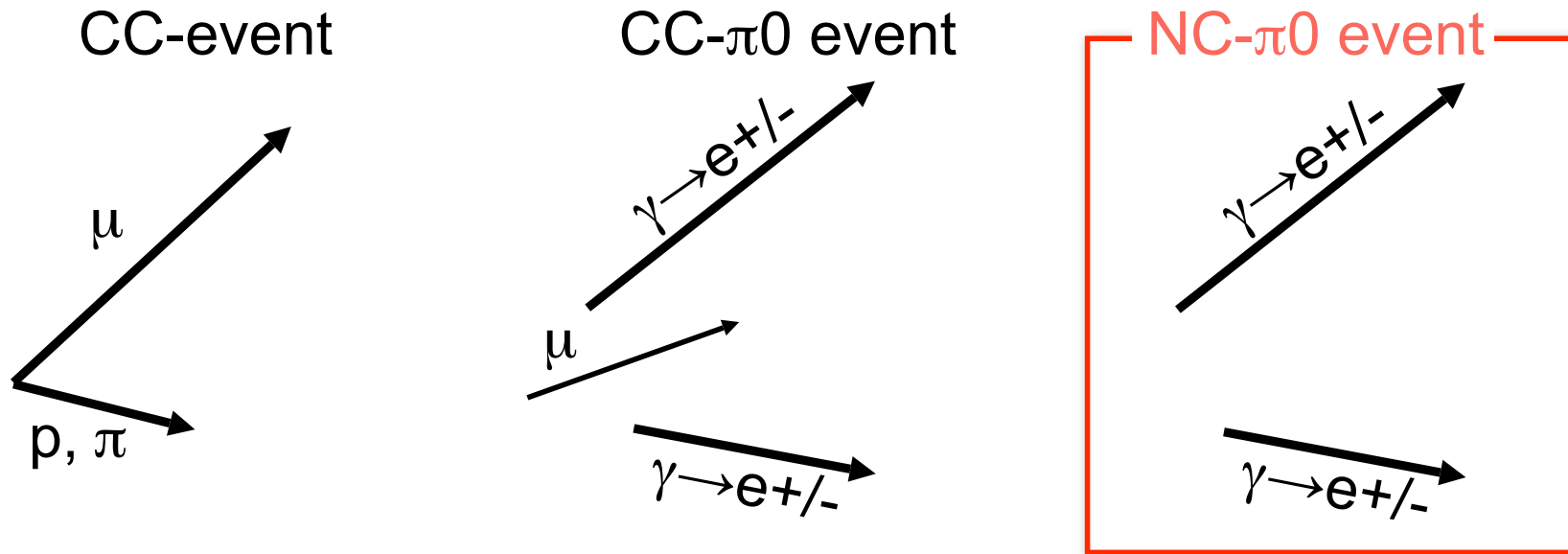
Signature of NC- π^0 event at SciBooNE

- No muon = No SciBar track go through MRD
- All tracks contained in SciBar

NC- π^0 : $\nu + N \rightarrow \nu + N + \pi^0$

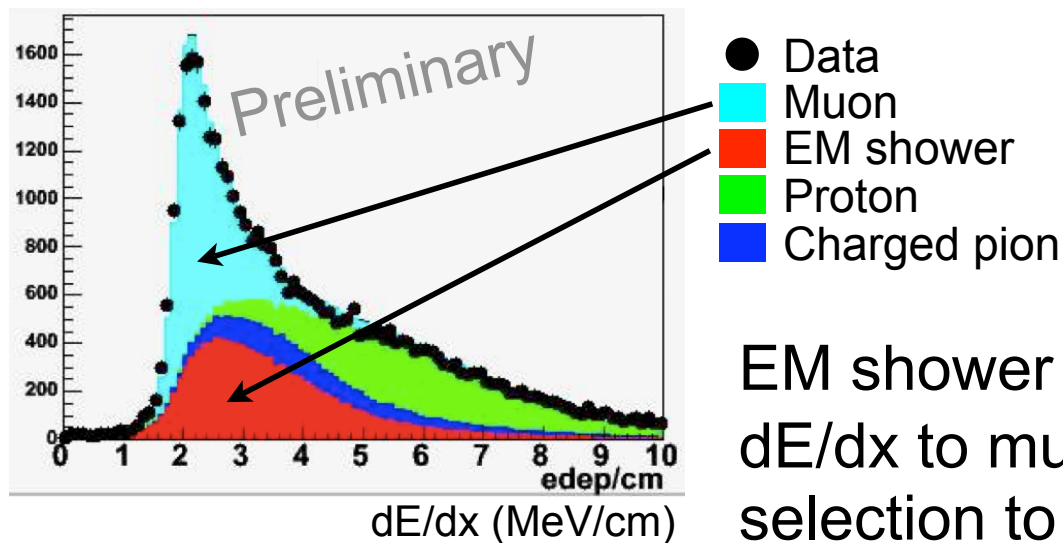
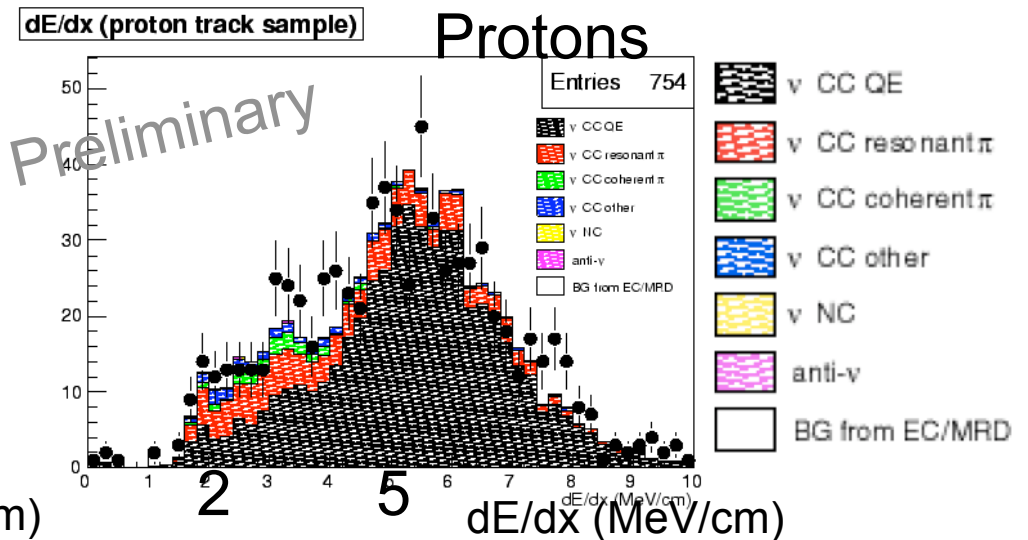
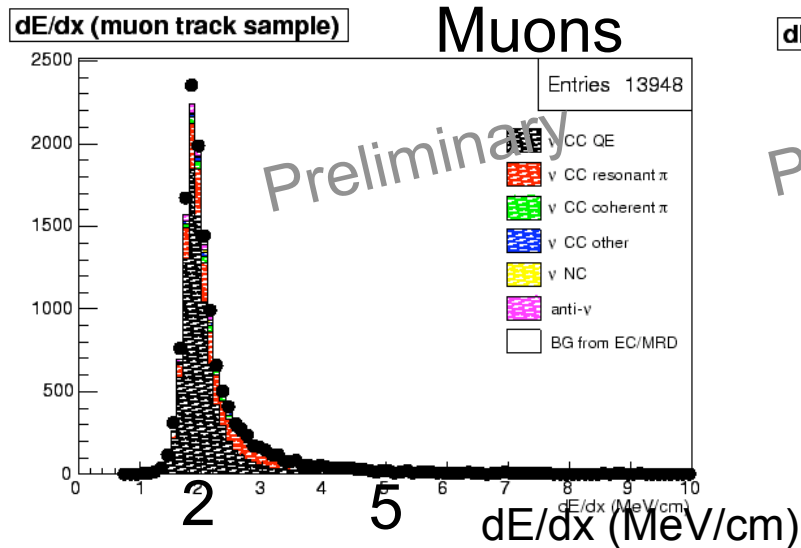


NC- π^0 event selection



- **NC- π^0 event selection**
 - Search γ tracks
 - **Particle ID -- Reject:** μ, π, p
 - Event topology
 - **Select two isolated tracks**

Particle ID with dE/dx

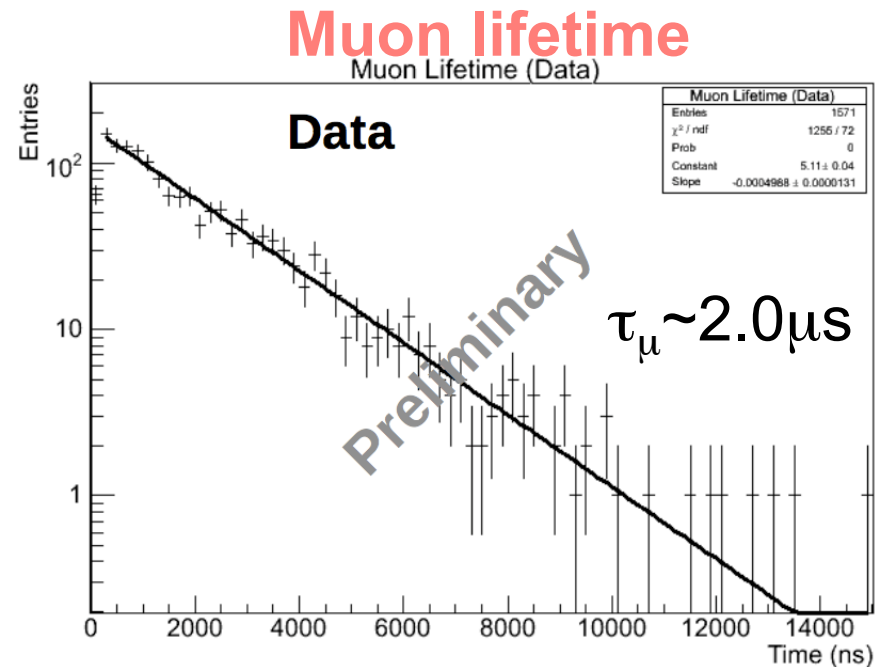
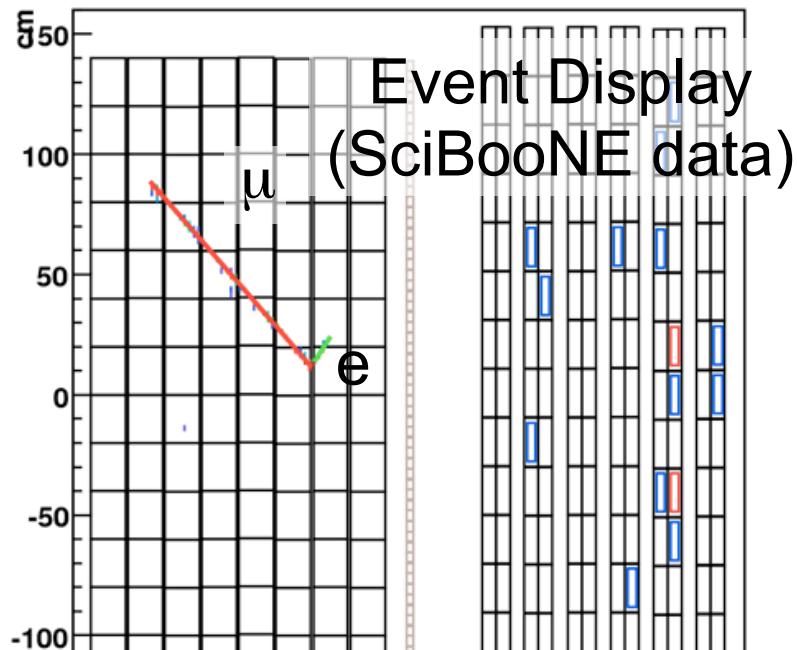


EM shower ($\gamma \rightarrow e^+e^-$) make similar dE/dx to muons. Need additional selection to reject muon (CC event)

Particle ID with timing info:

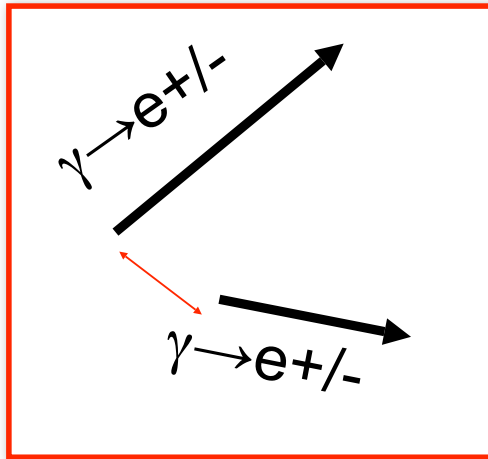
Muon identification

- Find out muon track → CC event rejection
- Tag decaying muon ($\mu \rightarrow \nu_s + e$) with SciBar TDC info: hits from muon and electron
- Clear signature of decaying muon.

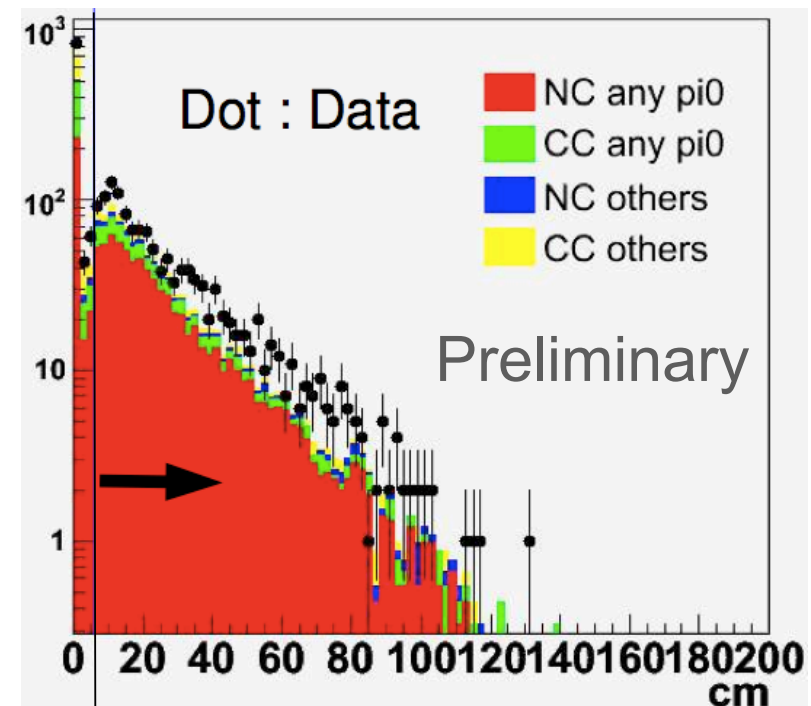


NC- π^0 event selection

-Event Topology-



- Select two isolated tracks

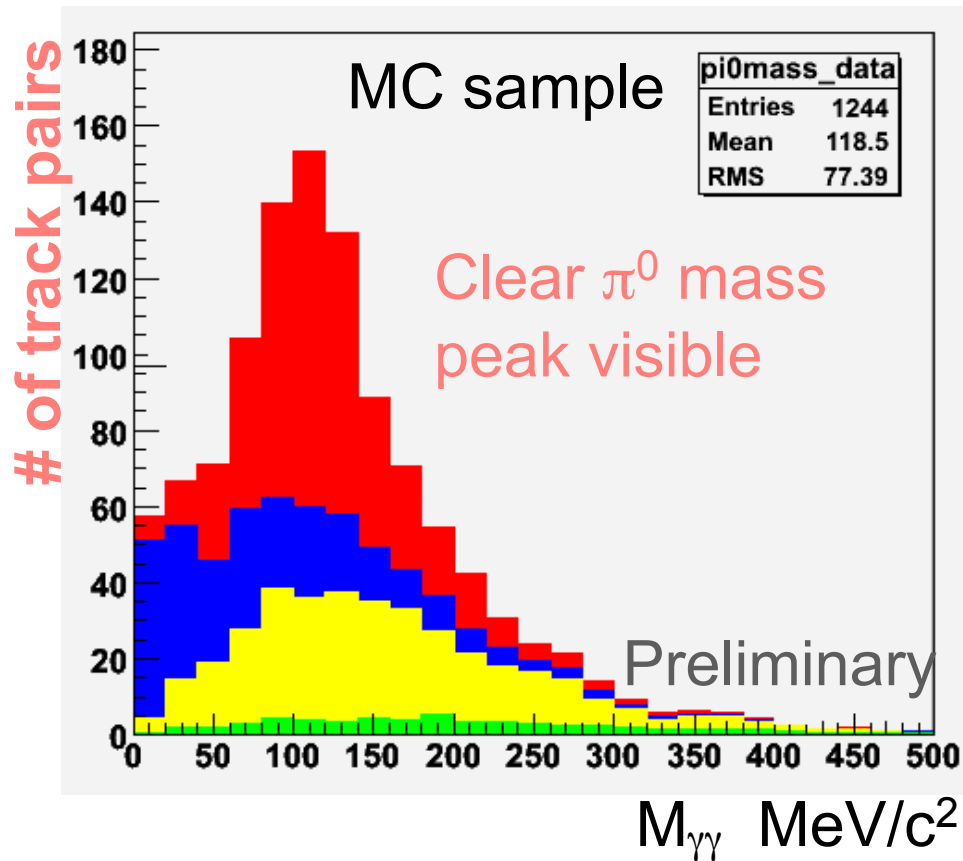


CC and
non- π^0
events

NC- π^0 enriched sample

**71% pure NC- π^0
sample**

Reconstructed π^0 mass



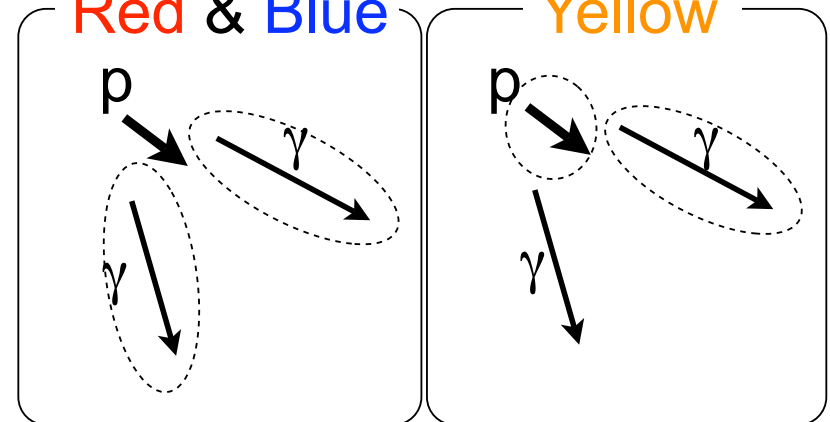
- 2 γ (from π^0)
- 2 γ (wrong γ combination)
- 1 γ & non- γ
- 2 non- γ s

NC- π^0 sample

involve 2 γ + **proton**

Red & Blue

Yellow




- Clear π^0 mass peak only from right combination of gamma tracks

Data will be released soon!!

Summary

- NC- π^0 cross section at low energy is crucial for ν oscillation experiments.
 - Major background to ν_e appearance search
- New results of cross section measurements
 - **K2K-1KT, MiniBooNE**
 - **High statistics and precision measurements.**
- Dedicated $\sigma(\nu)$ programs with fine-grained detector
 - **SciBooNE**: Analyses in progress and result in this summer!
 - **MINER ν A**: starts data taking in 2009!
- Lot of activity over past year!
- Opening door of new era in $\sigma(\nu)$ measurements



Thank you for your attention!

and

Congratulations to Spain!!